Automated Construction Field Data Management System

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A recently completed research project performed for the Indiana Department of Transportation (INDOT) to define and describe an automated construction field data management system is summarized. INDOT's field personnel typically spend 4 to 5 hr daily processing paperwork. The paperwork burden has reached a point where it distracts field personnel from performing their main task of supervising construction. This is typical of other state departments of transportation. The purpose of the project was to define a system that could be developed to ease this problem. In this project, current INDOT data management procedures and software systems were reviewed, a survey of other department of transportation field data management systems was performed, computer hardware and software tools were explored, system requirements were determined, and costs and benefits were calculated.

Department of transportation (DOT) construction supervision personnel spend a considerable amount of time processing construction data (construction data include material and test data), sometimes to the extent that it distracts them from their main task of directing and supervising the construction process. A recently completed research project for the Indiana Department of Transportation (INDOT) indicated that on a construction project the inspector and project engineer (PE) typically spend 4 to 5 hr daily processing paperwork (1). On the basis of existing trends of increased construction activity without parallel increases in INDOT personnel, data management will continue to expand, making more demands on time. Results of a survey performed under the INDOT research project indicate that the same scenario is occurring in other state DOTs. Not much can be done to reduce the amount of construction data generated and managed, but an innovative automated data management system could be developed to solve this problem.

DEVELOPMENT OBSTACLES

Typical obstacles that will probably be encountered during system development include lack of data integration within a DOT organization, hardware and software considerations, servicing the system user, overcoming the burden of DOT paper forms, and determining how to phase in automation.

A common problem among DOT organizations is the lack of integration between various data systems. For example, computer systems may exist within accounting, design, contracts, maintenance, materials and tests, and construction. Usually each operates as a stand-alone product with no link to the other systems. This has created "islands of automation" within a DOT organization. An effort needs to be made to link these data islands together to share information. Figure 1 shows these two data automation configurations.

To achieve integration between systems, an interface must exist. This interface is accomplished through hardware and software at the various user levels. Other factors affecting integration are the size of the DOT, its organizational structure (i.e., projects, districts, and central), personnel computer capabilities, user resistance, and organizational demands on the data.

To mitigate user resistance, the system should be designed around the users. Input should be solicited from the field, district, and central office personnel so that a user friendly system results.

Another obstacle is the process of going from paper to electronic forms. To expedite this, all pertinent forms should be studied. Each form should be reviewed to determine whether it will be needed and how it will be represented in the system. The study should also document the paths of forms so that electronic data trails can be designed.

User acceptance can be enhanced through staged implementation. Bringing the system on line on one project, several projects, or a district at a time will help to reduce start-up problems and user rejection.

CURRENT SYSTEMS

One activity of the INDOT research project was to survey other state DOTs to determine whether a system existed and to obtain a description of it. A survey was sent to 50 DOTs, and 44 were returned. Thirty-one DOTs indicated that a system was either operational or in some stage of development. Table 1 summarizes the responses of these states.

Software varied from a data base package such as dBase III+, to a higher, more powerful language, such as C. IBM PCs or compatibles were the machines used in the field, and those that transferred files electronically were equipped with modems. Hardware used at other levels varied from a PC to a mainframe. The mainframe and mini are used mainly for processing and data storage. In-house development costs averaged $100,000 to $400,000, and outside consultant costs went into the millions of dollars.

Currently (1991), the American Association of State Highway and Transportation Officials (AASHTO) is pursuing the development of a construction management system. This system will integrate with BAMS, another AASHTO software product, and provide some of the features identified in this

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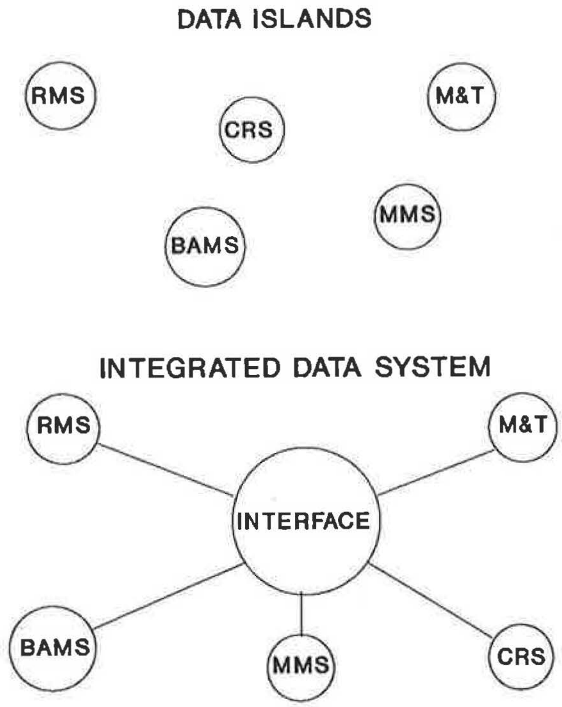

RMS - Roadway Management System
BAMS - Bid Analysis Management System
MMS - Maintenance Management System
CRS - Construction Record System
M&T - Materials & Test System

FIGURE 1 DOT data systems.

paper. The system will be mainframe based with PC tie-in from the field office. The purpose of the system is to computerize field operations by automating the paperwork process (*2*).

CONNECTICUT DOT SYSTEM

Perhaps the most mature system is found in Connecticut. In 1985 a $5 billion rehabilitation program began that burdened the existing construction data management system. To deal with this problem, CONDOT contracted with a consultant to design and develop a system. Development took 2 years, and the system went on line in summer 1988. Before the rehabilitation program started in 1985, approximately $80 million was spent each year on highway construction. CONDOT spent $750 million in 1990 for construction on approximately 250 projects. Approximately 400 CONDOT personnel are involved in supervising construction. Approximately 40 percent of the projects are managed by consultants, so in 1990 CONDOT will supervise approximately $450 million in construction with approximately 400 personnel.

To deal with this construction supervision problem, several management systems were identified and developed: the construction management and reporting (CMR) system, the preconstruction management system (PCMS), the executive reporting system (ERS), and the financial management information system (FMIS).

The CMR system is a PC stand-alone and interactive terminal system. Each project office is connected to the central office UNISYS mainframe via dedicated phone lines. Each workstation provides the user access to the CMR system as well as local data processing. Local computing capability includes spreadsheet, electronic memo or mail, and some engineering calculation capability. The Federal Highway Administration (FHWA) is tied into the system. Any field consultant can access the system as well. The system is ID and password protected.

The ERS is an information overview system used by upper management. Information used by the system is updated every night. This system is visually operated by using colors and the touch screen. Colors are used to indicate project condition on the basis of certain parameters (personal interview with A. Gruhn, CONDOT, 1990).

SYSTEM FEATURES

General system capability is the automation of construction field data. Initially this should encompass the capture, storage, and transfer of daily field-generated data, materials and test data, processing reports, and contractor payments.

Data integration should be a dominant system characteristic. Data collected and used in this system should be stored in a format that is accessible from other DOT computer systems. The hardware configuration should allow for the sharing of data between the various systems.

Hardware Configurations

On the basis of the previously mentioned premise of data integration, and because most DOTs use a mainframe and are organized by districts, three hardware options are considered feasible:

1. All storage and processing are handled on the mainframe. The PC acts as a terminal. Data accessibility is controlled at the mainframe by specifying user access codes. Communication costs are high because it is on line and interactive.
2. The mainframe is used as a storage device with processing required for managing the data base and communicating with users. Data reside at the mainframe, whereas the major processing is done at the PC level. PC acts in stand-alone and terminal environments. Stand-alone provides the user with additional computer capabilities. Processing the data at the PC lessens dependence on the mainframe. With batch transfer, communication costs can be greatly reduced. Batch transfer can be scheduled on a daily basis so that information is available the next day.
3. The mainframe is used as a storage device. At the district level a mini system will reside where data are received from the projects, stored temporarily, processed, and eventually stored on the mainframe. The PCs in the field do not communicate with the mainframe but go through the mini in the district. This lessens dependency on the mainframe so that users can operate in case it is down.

Option 3 was recommended to INDOT and is shown in Figure 2.

TABLE 1 State Responses to Survey

State	System Description
Alaska	Project Records Management Automated Weigh System
Arizona	Conceptually designed, awaiting funding.
Arkansas	Computerized Estimating system, PC based. Portable data collectors for inspectors.
California	Progress payment system, main frame based.
Colorado	Considering AASHTO's Construction Daily records program.
Connecticut	Operational system developed by consultant.
Illinois	Conceptual stage, PC based system.
Iowa	Conceptual stage.
Kansas	Developmental stage. Using consultant. PC at job site , data transfer to main frame.
Kentucky	Operational PC stand-alone system. DBase III+ compiled programs.
Maine	Some PCs in the field office with customized applications. Lab testing automation currently underway.
Maryland	Operational PC stand-alone system. DBase III+ compiled programs. Inspector's daily report data tracked.
Michigan	Operational stand-alone system. DBase III+ programs that processes project records, pay estimate,and tested materials.
Minnesota	Contract Administration Record System. Used to process pay requests. PC based.
Missouri	Operational system. DBase III+ programs that process the daily report.
New Hampshire	Developmental stage. PC based system, C language, fully automated system with tie-in to mainframe.
New Jersey	Automated Construction Estimate System(ACES). DBase III+ programs for producing monthly estimates.
North Carolina	Conceptual stage. PC system linked to main frame.
North Dakota	Operational system. PC stand-alone dBase III+ programs. Used for record keeping.
Ohio	Survey stage. Form study underway. Automate daily records and testing reports. Hired consultant.
Oregon	Continuing developing a system that will create an automated construction/maintenance system.
Pennsylvania	Operational documentation system. DBase III+ programs with electronic data transfer capability. Material and test system under development.
South Carolina	Developing construction system tie-in to BAMS.
South Dakota	Conceptual stage.
Texas	Interested in AASHTO's construction records program.
Vermont	PC field bookkeeping system. BASIC language.
Washington	Contract Administration payment system is operational. Construction Contract Information System operational - PC and main frame based. Developing materials and test program.
Wisconsin	Operational system. Daily work items tracked and monthly estimate produced. PC based with data transfer to main frame.

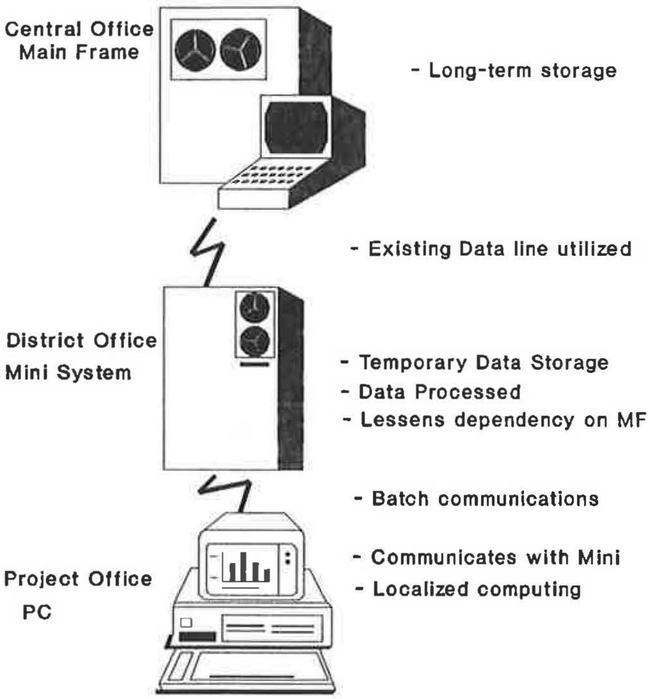

FIGURE 2 Hardware Option 3.

FHWA Guidelines

Since the system will be used on projects that fall under the jurisdiction of FHWA, certain established FHWA guidelines must be complied with (*3*). The guidelines are as follows:

- Provide for adequate backup and recovery of records to protect against information loss. Protection procedures should be in place to prevent both human and system failures.
- Prevent unauthorized alteration or erasure of electronic records.
- DOT must validate equipment reliability when records are created.
- Accurate audit trail must be present.
- Adequate data storage backup must be in place.

PC Computing

Computing capability should be available to the user at the PC level. Capabilities provided would give the user local computing capability and allow for user-developed personalized applications. At a minimum, the following software should be available: spreadsheet capability, data base manager, electronic mail, word processing, and volumetric calculation capability for earthwork and concrete calculations.

Miscellaneous Features

The features mentioned in this section are applications of some of the latest technologies in data management. These features act as accessories and could be a part of the initial system or phased in so that ultimately a paperless system could exist. A short description of each is provided.

Computerized Specs

Electronic specs means that the standard specs, supplemental specs, and special provisions will be stored and maintained in electronic form and made accessible to users. The user should have the ability to manipulate, process, and use the specs.

Portable Data Collectors

Using hand-held portable data collectors in the field brings automation to the data collection process. The portable device can be used to record testing, inspection, material delivery, or any information recorded remotely. The data can be batch uploaded into a PC for processing.

Asphalt/Concrete Plant Tie-In

Batch plant data such as batch numbers and weights can be recorded and transmitted electronically, eliminating most of the time and labor required in the manual process.

RF Tags To Record Quantity Installed

Radio frequency (RF) systems can be used to track and record hauled construction quantities. Tags that store hauled weight and number of trips are affixed to hauling units. This information is inscribed on the tag by passing the unit over a scale and RF scanner that writes it on the tag. The hauling unit essentially has a portable data base attached to it from which data can be retracted and uploaded into the data management system. This would eliminate the need for an inspector to count and measure quantities.

Bar Code Usage

Forms that have recurring fields of data could probably benefit from bar codes. Bar coded labels could be attached to testing samples and used to identify and track them through the testing process. Also, bar coded menu tablets could be used to quickly enter data into the computer. Use of bar codes can significantly improve data entry speed and at the same time reduce data entry error. The only equipment required would be a reader or scanner and software that can print the bar codes on the documents or labels.

Laboratory Equipment RS232 Interface

Laboratory and testing equipment can be equipped with RS232 ports so that data can be captured electronically into a computer system. This would eliminate manually recording the information and keying it into a computer.

Electronic Signature Control

Signature authorization is required to process many DOT forms, especially contractor progress payments. Technologies are available that provide this capability electronically. One is a plastic magnetic stripe card that is scanned when authorization is required. Another is touch screen technology, by which signatures can be recorded onto electronic documents.

Document Scanner

Use of document scanners is a way to quickly enter paper documents into electronic form. Certain forms and processes may lend themselves to this technology.

Electronic Clipboard Capability

With this device, field personnel can record information electronically much like they would with a clipboard and paper. Ideal applications are recording inspection information and drawing sketches electronically. This information can be uploaded into the data management system.

Initial Capabilities

All of these capabilities or features can be components of the system, but it may too complex and unnecessary initially. The system is conducive to staged development and implementation.

SYSTEM COSTS

System cost comprises software development, hardware, software, communication, system and hardware maintenance, data processing staff support, and training.

Software Development

Developing software could be the largest initial cost. Basically, three options exist, with some variations possible for each: consultant developed, in-house developed, and hybrid (in-house and consultant).

An outside consultant provides expertise and experience that potentially could produce a better product. Consultants usually have the manpower to devote to a project, so development time could be shorter. On the flip side, development costs will be higher.

Using in-house personnel to develop a system will be less expensive, but other factors must be considered. The availability and experience of data processing personnel to work on a project of this magnitude may be limited. This may cause a longer development time. But long-term maintenance support for the system may be better than a consultant because of internal system knowledge.

The third possibility is to have a mixture of in-house and outside consultant to supplement the development effort. The consultant provides additional expertise and experience, and DOT personnel can maintain more control over the final system makeup. This combination should also reduce costs.

After the system is operational, a system user depository should be established to incorporate user suggestions into future system revisions.

Hardware

Hardware components will be required at the various levels of the DOT organization. Equipment at the project site should include PC, monitor, printer, and modem. The modem is for transferring files between the field and district.

Hardware configuration Option 3 uses hardware at the district level for storing, processing, receiving, and sending data. Depending on district size and construction volume, the number of off-site users could range from 20 to 100. This hardware should not only support external users via phone lines, but also local network capability at the district office and communication with the mainframe. Most mini systems have this capability.

Software

Software will be needed at the PC for the system and localized computing capability, at the mini for data base management and communication, and at the mainframe for data storage. Software for local computing should include spreadsheet, data base management, electronic mail, word processing, and miscellaneous engineering calculation capabilities. Instead of buying software for each PC, it could be provided by the mini more economically. Other software needed at the mini is PC and mainframe communication and operating systems.

Communication

Transferring data from the field to the district or to the central office mainframe will have associated costs. The costs will depend on the frequency, duration, and distance of transmission. The options available are business telephone line with modem, dedicated data line, and the integrated digital services network. The business line and modem with batch processing is the most economical of the three options. A dedicated data line provides better data transmission but is much more expensive. A hypothetical economic comparison of these two options involving 300 INDOT projects indicated an annual cost differential of $1,500,000. The integrated digital services network is not as expensive as the dedicated line service, but in most states it is only available in limited areas.

Miscellaneous Costs

Costs from other sources will occur. Hardware and system maintenance, service, and update will be needed. A training program will be necessary to implement the system. This should consist of developing a training manual and conducting training sessions for system users. Securing project site hardware with extra locks, window bars, and other precautions will be another cost.

SYSTEM BENEFITS

The adoption of such a system will bring many benefits to a DOT. Most are hard to quantify but nevertheless will occur. The following are among the benefits: decisions will be based on complete information; the quality of information will be consistent; duplication of effort in recording and saving data will be eliminated; a better construction claims recording system will be provided; audit trails will be better defined, making it easier to track information; forecasting and trend analysis will be easier; accessibility of test results will be improved; credibility of data will increase; FHWA and consultant will have a tie-in; paperwork processing time will be reduced; supervision cost will be reduced; and the PE will be free of the paperwork burden.

Because valuable data will become easily accessible and retrievable, the following will be possible:

- More accurate future cost estimates,
- Tracking and processing of constructability data,
- Improved estimated quantities capability,
- Improved project duration estimates,
- Better tracking of roadway and structure status for construction and maintenance planning,
- Contractor performance records, and
- Ability to tie in to FHWA data base of information.

Savings will occur in postage, paperwork, form printing and storage, permanent record storage, management inquiries, and quality of the constructed project.

States that have developed and are using this type of system have documented some time benefits. In Connecticut, a pay estimate would take a PE 1 week at 75 percent time; now it is performed in 1 to 2 days. Stated earlier was that on an INDOT project about 5 hr per day is spent on paperwork. Of this time, 3.5 hr was spent by the PE. In comparison a PE in Connecticut spends 1 to 2 hr per day on paperwork. In New Jersey, by the manual method, it would take 1.5 hr to produce a daily report, 1.5 hr to produce a weekly report, and 4 hr to produce a monthly estimate. With the automated system these same reports are produced in 10 min, 15 min, and 20 min, respectively. Missouri DOT says its system is saving $0.5 million a year with improved accuracy.

CONCLUSIONS

Development and implementation of the system will require a considerable amount of effort, coordination, and cooperation. But before this system can become reality, it has to be perceived by management as necessary and a priority. Two realities should not be overlooked. One is that with transportation facilities continuing to deteriorate and heavier use expected, more construction will be needed to keep pace with demand. Second, because of a shrinking work force, fewer DOT personnel will be available to manage construction projects. These realities should demand the development and use of an automated construction data management system.

ACKNOWLEDGMENT

The author thanks the Indiana Department of Transportation for funding and the cooperative assistance he received in performing the project.

REFERENCES

1. B. G. McCullouch. *Automated Construction Data Management System*. 1991.
2. AASHTO Construction Subcommittee Task Force. *Construction Management System User Requirements*. AASHTO BAMS Users Group, 1991.
3. *FHWA Guidelines for Field Office Computerization*. FHWA, U.S. Department of Transportation, 1991.

Publication of this paper sponsored by Committee on Construction Management.